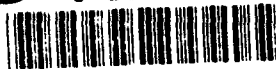# A General Theory of Signal Integration for Fault-Tolerant Dynamic Distributed Sensor Networks
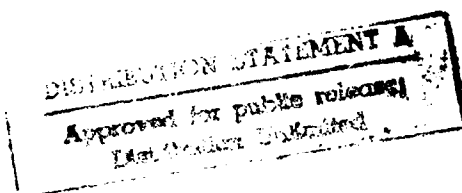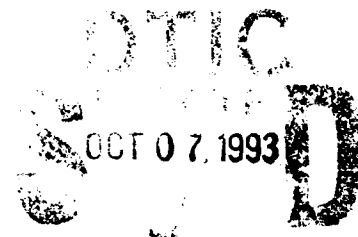
ONR GRANT NO: N0014-91-J-1306

RESEARCH SUMMARY
1992-93

Professor S.S.Iyengar
Professor B.J.Jones

October 1,1993.

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Brief Introduction:

The computational issues related to information integration in multisensor systems and distributed sensor networks has become an active area of research. In recent years a number of significant advances in the field of sensor integration have been made. This interest in the development of Distributed Sensor Networks(DSNs) for information gathering has partly emerged because of a) the availability of new technology which makes the DSNs economically feasible to implement and b) the increasing complexity of today's information gethering tasks to which they are applied.

From a computational viewpoint, the efficient extraction of information from noisy and fault signals emanating from many sensors requires the solution of problems related to a) the architecture and fault-tolerance of the distributed sensor network, b) the proper synchronisation of sensor signals, c) the integration of information to keep the communication and the processing requirements small, and d) the design of efficient computational techniques to abstractly represent and integrate sensor information.

Wavelet based sensor integration:

Multiresolution analysis can be used in filtering out robust peaks in the overlap functions obtained from abstract sensors to produce fault tolerant sensor estimates in Distributed Sensor Networks. This technique is most effective when the number of sensors is very large and the number of tame sensors is also large. The idea essentially consists of constructing a simple function from the outputs of the sensors in acluster and resolving the function at various successively finer scales of resolution to isolate the region over which the correct sensors lie.

Topics of current research:

The following issues have been the subjects of our current research:

1) Wavelet based distributed sensing and fault tolerant sensor integration.
2) Computational frameworks for distributed sensing and fault tolerant sensor integration.
3) Design of fault-tolerant architectures for distributed sensor integration.
4) Computational complexities of the problem of distributed detection.
5) Issues related to recording of events and synchronization in distributed sensor networks.

Attached to this report is a list of publications resulting from this research.

Books

1. **Distributed Sensor Integration :** S.S.Iyengar, Hla Min and L.Prasad (To appear)

2. **Introductory Theory of Wavelets with applications :** L.Prasad and S.S.Iyengar. (in preparation for possible publication in Prentice Hall)

RESEARCH PUBLICATIONS

List of papers accepted/published in refereed journals:

1. S.S.Iyenagr, M.B.Sharma and R.L.Kashyap "Information Routing and Reliabilty Issues in Distributed Sensor Networks" **IEEE Trans. on Signal Processing,**Vol 40, No 12,Dec. 1992, pp. 3012-3021.

2. Raj Narayan, S.S.Iyengar, R.Sridhar and R.L.Kashyap "An Optimal Distributed Algorithm for recognizing Mesh-Connected Networks" **Journal of Theoretical Computer Science,** Vol 119,November 1992.

3. L. Prasad and S. S. Iyengar "An Asymptotic equality for the number of neclaces in a shuffle exhange network", **Journal of Theoretical Computer Science,** Vo'. 102, pp 355-365, 1992.

4. S. S. Iyengar, D. N. Jayasimha and D. Nadig " A versatile Architecture for the Distributed Sensor Integration Problem", To appear in **IEEE Trans. on Computers** (june 1993).

5. S. V. N. Rao, S. S. Iyengar and R. L. Kashyap " Computational Complexity of the Distributed Detection Problem", to appear in **Journal of Computers and Elec. Engg.** (June 1993).

6. R. Sridhar, S. S. Iyengar and S. Rajanarayanan, "Range Search in parallel using Distributed Data structures", **Journal of Parallel and Distributed Computing,** Vol 15, No 2 1992, pp 70-74.

7. S. S. Iyengar and F. B. Bastani, "Self-organizing Knowledge and Data Representation in Distributed Environment: An Introduction", **IEEE Transaction on Data and Knowledge Engineering",** Vol 4, No 2, April 1992, pp 105-107.

Paper under revision:

1. L. Prasad and S. S. Iyengar " A General Computational Framework for Distributed Sensing and Fault-Tolerant Sensor Integration", Submitted to **IEEE-SMC.**

List of Papers submitted to refereed journals

1. V. G. Hegde and S. S. Iyengar " An efficient Distributed Algorithm to find Biconnected Components of an Asynchronous Network", Submitted for publication to **Information Processing Letters.** Also, technical Report TR-92-015, Dept. Of Computer Science, LSU.

2. S. S. Iyengar and D. Nadig, "Using Temporal Intervals for Synchronization in Real Time Distributed Systems", Submitted to **Electronic Encyclopedia**.

3. V. G. Hegde and S. S. Iyengar "Efficient Distributed Planarity Testing Algorithms in the Context of DSN", Submitted for publication.

4. B. Jones and S. S. Iyengar " Root Isolation for Non Linear Equations", Submitted for publication to **International Journal of Systems Theory.**

5. L. Prasad, S. S. Iyengar, R. L. Kashyap and R. Rao "Fault-Tolerant Integration of Abstract Sensor Estimates Using Multi-resolution Decomposition", Submitted for publication to **Physical Review**.

6. W. Deng and S. S. Iyengar "A New Probability Relaxation Scheme and its applications to Edge Detection", Submitted for publication to **IEEE-PAMI**.

List of Papers in refereed conference proceedings:

1. B. Jones and S. S. Iyengar, " Information Theoretic Contributions of Components in Distributed Sensor Networks", **Proceedings of the thirty sixth annual meeting, International Society for the System Science**, Denver, Colorado, July 12-17, 1992.

2. L. Prasad and S. S> Iyengar, "A General Computational Framework for Distributed Sensing and Fault-Tolerant Sensor Integration", **Proceedings of the IEEE Southcon Conference**, March 1992.

3. D. Nadig and S. S. Iyengar, " A New Architecture for distributed Sensor Integration", **Proceedings of the IEE SouthEast Con**, April 1993.

4. S. Trivedi, B, Jones and S. S. Iyengar, "A System Theoritical Approach to Generalized Rule Induction from Databases," Submitted to **6th ACM conference on Computational Learning.**

Invited Talk:

Indo-US Workshop in Computer Science, August 4-6, 1992, Bangalore, India,

University of Paris, France, March 1993.

Research Papers in progress:

1. Spline Wavelets : A New Approach to Finite Impluse Responce (FIR)
   Filter Design.

2. Wavelet Based Distributed Sensing and Fault-Tolerant Sensor Integration.

3. Scaling and Temporal Characterization of Sensor Integration Problem in
   Distributed Environments. This is is an extension of Dr. Madan's work on
   Maximum Entropy techniques.

4. Interval-based Synchronization in Real-Time Distributed Sensor Systems.

5. Distributed Conferencing System for 2D graphics Design.

Graduate Students involved (Ph. D Program).

1. L. Prasad

2. D. Thomas (EPSCOR - DOD Program)

3. W. Deng

4. S. Trivedi

Distributed Sensor Networks
(Professor Bush Jones contribution)

The research performed thus far consists of three components. The first component is a system model with a maximum entropy characterization. For a complex system, the characterization becomes nonlinear , and it becomes nec essary to solve a set of nonl;inear equations for all roots in aprescribed region. There is no current methodology to effectively isolate such roots, so the second component of the research is a new technique to isolate roots of a nonlinear system of equations. The third component is a by-product of this reseaich. A more accurate represenbtation of statistical interactions is proposed and compared to statistical interactions.

Three papers have been prepared. The system model has been published by Jones and Iyengar in the ISSS conference proceedings. The root isolation technique is a definitive work with broad application by Jones and Iyengar that is currently being revised for publication in Computers and Mathematics. The interaction concept is an invited paper by Jones and Gouw for the IJGS journal. All three papers acknowledge ONR support.

Part I. System Model

This research provides a system's model for a network for a network of sensors. A set of sensors with associated information processing nodes is viewd as an overall system. Within this overall system are subsystems of sensors and information processing nodes. An arbitrary overall behavior function (which may or may not be analytically provided) describes important reactions of the systems to inputs at the sensors. From the overall behavior function, functions for the subsystsms are generated. Analysis using entropy mathematics makes possible the identification of important subsystems and their characterization. The analysis uses information theory, and measures the information theoritic contributaion of a subsystem to the overall system.

A program has been written which will take as input a descriptin of a sensor network, and will output the informtion theoritic importance of the major subsystems based on linear mathematics. Subsequent work treats nonlinearities.

Part II. Nonlinear Equations

This research provides methodology and a program for isolating the real roots of nonlinear systems of equations. The technique developed requires only function values, and can be applied to any nonlinear system. The technique has broad application wherever nonlinear equations arise. The technique and program have been empirically tested for effectiveness and efficiency. This research constitutes a definitive work in nonlinear equations.

Part III: Interaction Concept

This reseach provides a more accurate representation of interactions than is found in classical statistics. A description of the interaction concept is given, and it is compared to the classical statistical interaction that is based on linear mathematics. An example is given which reveals wide disparities in interaction results.